

AMMONIA REMOVAL BY AIR-STRIPPING

A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY



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BY
GODAVARTHY RAMPRASAD

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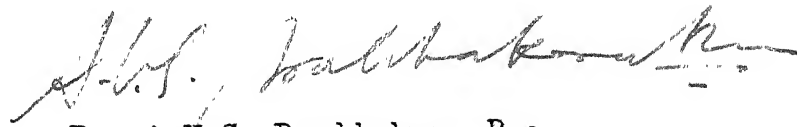
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DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
JULY 1970

CERTIFICATE

This is to certify that the present work has been done under my supervision and the work has not been submitted elsewhere for a degree.



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G RAMPRASAD

SYNOPSIS

From the present study it is firmly believed that the method of air-stripping of ammonia has a good potential for treating fertilizer factory waste which can not be treated by conventional methods due to high ammonia concentration. Controlled experiments have been conducted with synthetic samples to obtain basic data regarding the factors affecting the air-stripping of ammonia. Rate of removal of ammonia has been found to be increasing with pH only upto a pH value of 11, whereafter the increment is negligible. Rate of removal has increased with temperature and rate of aeration. Initial concentration of ammonia nitrogen has no effect on rate of removal of ammonia. High urea concentrations that are usually encountered in fertilizer factory wastes also have no effect on air-stripping of ammonia. Similarly changing the ammonia source in the synthetic sample has no effect on rate of removal. Compared to sodium hydroxide, lime is found to be unfavourable to increase the pH of ammonia solution.

CHAPTER I

INTRODUCTION:

1.1 Increasing industrialisation of the country brings in many problems of environmental and health hazards. The adverse effect of industrial pollution on natural resources, especially on water, has far reaching consequences. While on one hand one is faced with the dwindling supply of pure water, health hazards due to chemicals and pollutants and depletion of aquatic life, on the other hand industries themselves are facing the water shortage for their processes, not to mention the requirement for domestic purposes.

In the recent years the demand for fertilizers as a consequence of 'Green revolution' prompted the establishment of more fertilizer factories. While the produce of the factories is helping in the growth of more food, the wastes from the factories discharged into the natural waters are destroying fish and other aquatic life. The deleterious effect of fertilizer wastes is due to the nutritive value resulting in eutrophication of the receiving bodies. Abundant algal growths and meager dissolved oxygen levels resulting from decomposition of algae suffocate the fish, release obnoxious compounds and

makes the water unfit for use.

Observations in lakes (1) show that phosphate and ammonia contributed by the fertilizer wastes, can be used to the last ion by algae. An already occurring eutrophication by natural nutrient sources will be reinforced by introduction of these wastes. The fertilizer factory wastes have more nutritional value and cause water quality problems, resulting from the excessive activity of the photosynthetic organisms. Eutrophication needs a specific environment of light, temperature, turbulence and nutrients like nitrogen and phosphorons. Since control of physical factors is difficult, more stress is laid on nutrient removal (2) .

1.2 The excessive fertilization of river waters poses many serious problems. The decaying organic matter viz. dead algae, causes depletion of dissolved oxygen. The rooted aquatic forms use oxygen in the night and effect fish life. Excessive blooms of algae which float on the surface of water reach the shores where they die and release obnoxious odours (3, 4). The National Technical Advisory Committee of Water Pollution Control

Federation, U.S.A. (5) observed that ".....at pH levels of 8 and above, total ammonia expressed as nitrogen should not exceed 1.5 mg/l in order to protect fish life. This committee also mentioned that ammonia can be corrosive to certain metals and materials of construction. Ammonia causes trouble in chlorination of water also. Research has revealed (6) that the amount of rice crops is decreased due to excess nitrogen in irrigation waters. The maximum permissible content of nitrogen in the irrigation water has been mentioned as 10 to 20 mg/l. Methemoglobinemia in infants is caused by drinking water containing more than 20 mg/l of nitrates that are formed due to biological oxidation of ammonia (7).

To get rid of these troubles the high concentrations of nutrients like ammonia have to be removed from the fertilizer wastes before they are let into streams. Fertilizer factory wastes are not easily treated by conventional methods of waste water treatment (8), since they contain large concentrations of ammonia and urea, that are toxic to micro-organisms in such ion concentrations. There are large number of fertilizer factories

that are already existing and many more are coming up in near future. A list of these factories is given in Table No. 1 (9, 10).

TABLE NO.1
EXISTING AND PROPOSED FERTILIZER FACTORIES
 (REF. 9 and 10)

Name of the factory	Location	Capacity in Metric Tonnes
1. Nangal Fertilizers and Chemicals	Nangal (Panjab)	80,000
2. Not known	Gorakhpur (U.P.)	80,000
3. Unknown	Namrup (Assam)	1,52,000
4. Panki Fertilizer Factory	Kanpur (U.P.)	2,00,000
5. Unknown	Khota (Rajasthan)	13,000
6. Unknown	Barowni (Assam)	1,52,000
7. Hindustan Steel Ltd.	Durgapur (W.B.)	1,40,000
8. Alembic Chemical Works Ltd.	Baroda (Gujrat)	1,20,000
9. Hindustan Steel Ltd.	Rourkela (Orissa)	60,000
10. Unknown	Haldia (W.Bengal)	2,00,000
11. Esso Standard Inc. Refineries Ltd.	Trombay (Maharashtra)	1,24,000

12. Coramandal Fertilizers	Visakhapatnam (A.P.)	80,000
13. A.P. Fertilizers and Chemicals Ltd.	Kottagndem (A.P.)	61,500
14. Unknown	Goa	1,60,000
15. Unknown	Mangalore (Mysore)	2,40,000
16.(i) Premier Fertilizers Ltd.	} Madras (T.N.)	1,90,000
(ii) Madras Fertilizers Ltd.		
(iii) Madras Phosphate Manufacturers Pvt.Ltd.		
(iv) East India Distilleries and Sugar Factories)		
17. Neively Lignite Project	Neively (T.N.)	70,000
18. Fertilizers and Chemicals (Travencore) Ltd.	Alwaye (Kerala)	24,000
19. Unknown	Cochin (Kerala)	1,45,000
20. Sindri Fertilizer Unit	Sindri (Bihar)	20,000

CHAPTER II

SCOPE OF STUDY

Various methods are available to remove the high concentration of ammonia which include ion exchange, electrodialysis, nitrification-denitrification system and air stripping. Eliassen et al; (11) have given a comparative cost and efficiency structure of these methods. This information is tabulated in Table No. 2. Agarwal (8), Mujumdar (12), Maheswari (13) and Bhattacharya (14) have worked on nitrification-denitrification systems. Even though air stripping of ammonia removal has been cited as the cheapest, efficient and easy to work with compared to biological methods, no details have been given either in the paper cited (11) or in the available literature. It was felt that information on air stripping of ammonia would be useful for treatment of fertilizer wastes. Since basic information was not available for design and operation of this process, an attempt has been made in collecting information on the effect of pH, temperature, concentration of ammonia, rate of aeration and effect of urea found in the waste effluents. Feasibility of the study from theoretical considerations is described in the following pages.

TABLE NO. 2

COMPARISON OF ALTERNATIVE NITROGEN REMOVAL METHODS

Process	Removal efficiency	Estimated removal cost \$/mil gal.	Type of wastes to be disposed of.	Remarks
Ammonia stripping	80-98	9-25	--	Removal efficiency is based on ammonia nitrogen only.
Conventional biological treatment	30-50	30-100	Sludge	
Anaerobic Denitrification	60-95	25-30	None	
Algae harvesting	50-90	20-35	Liquid and sludge	Large land area required.
Ion exchange	80-92	170-300	liquid	Efficiency and cost depend on degree of pretreatment, coag., filt., etc.
Electro-chemical treatment	80-85	4-8 ^(a)	liquid and sludge	
Electro dialysis	50-55 ^(b)	100-250	liquid	costs based on 1 mgd-10 mgd capacity solids cone = 1,000 mg/l ^(c) .
Reverse osmosis	65-95	250-400	liquid	
Distillation	90-98	400-1000	liquid	
Land application	-- ^(d)	--	None	Large land areas required

a - on power cost only, installation costs unavailable.

c. cost data obtained from ionics, Cambridge, Massachusetts.

b - removal efficiency per single stage.

d. removal efficiency depends on form of nitrogen.

CHAPTER III

THEORITICAL CONSIDERATIONS OF AIR STRIPPING

Stripping is a physical process of mass transfer from liquid phase to the gas phase (15). By sending fresh air into ammonia solution, it diffuses into the air bubbles and escapes out. In this process three phases are involved in the total rate of ammonia removal (16). The first phase of transfer is during bubble formation at the interstitial openings of the aeration devices. In the case of aeration devices having large openings and high air-flow rates the mass transfer is negligible in this phase. The second phase of transfer is during bubble ascent to the surface. The amount of ammonia transferred during the ascent depends upon the mean surface area of all the air bubbles in ascent in the liquid, the concentration gradient and the overall diffusion coefficient of ammonia. The final phase of mass transfer takes place at the liquid surface when the bubbles escape. The disturbance of the free surface due to energy dissipation and the bursting bubble is responsible for ammonia transfer at the surface. It is investigated by

some authors (16) that mass transfer during this phase is negligible.

The course of ammonia removal is depicted in Fig. 1 in which concentration of ammonia is plotted against time. The mathematical expression for this plot may be given as

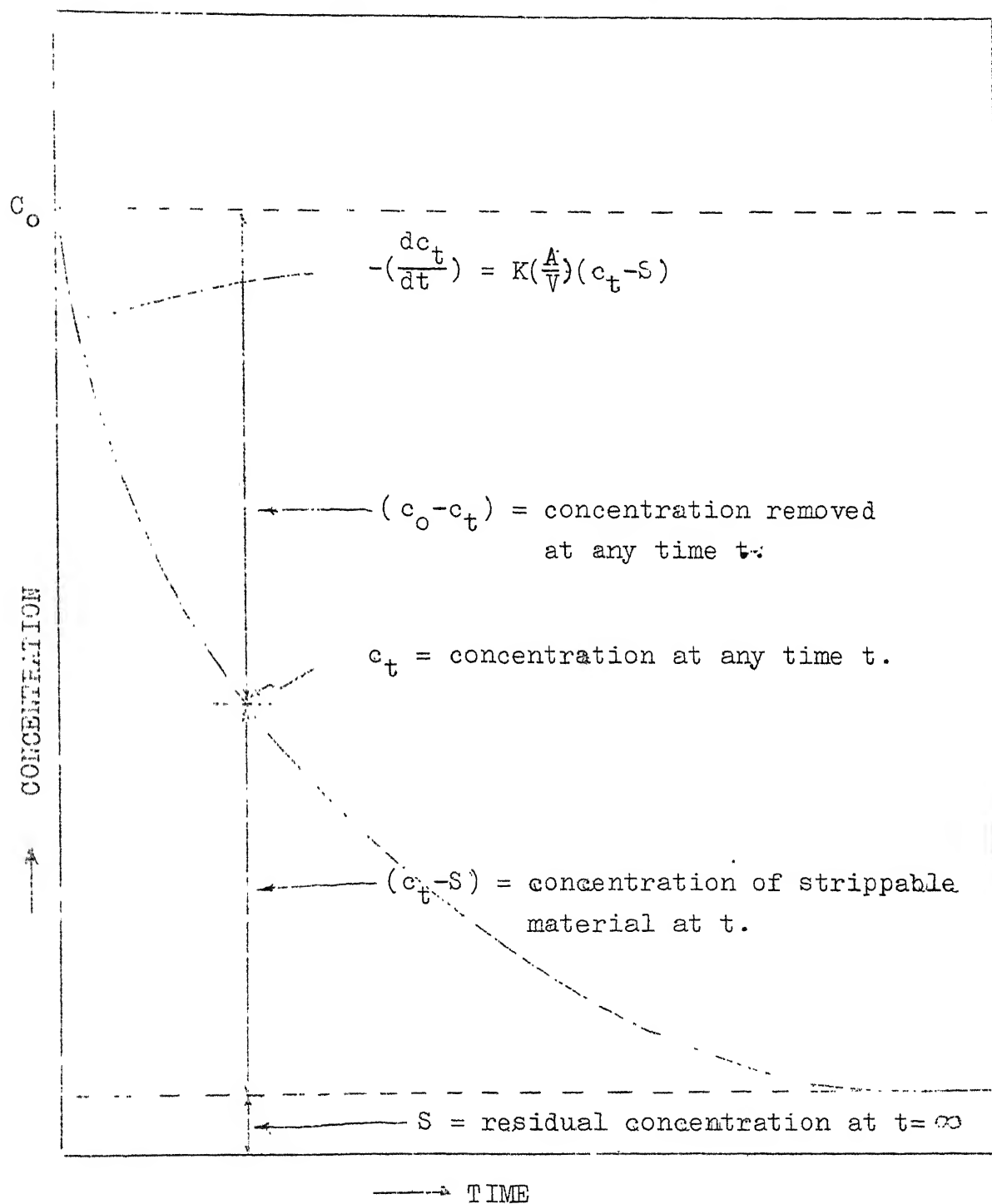
$$-\frac{dc_t}{dt} = K' \left(\frac{A}{V} \right) (c_t - S) \quad I$$

where c_t is the concentration at any time t , A is the area available for transfer, V is the total volume of liquid subjected to stripping and S is the residual concentration of ammonia that can not be removed even at infinite time. That means, the rate of change of ammonia concentration is proportional to the removable ammonia concentration at any time ' t ' and to the area available for transfer divided by the total volume of fluid subjected to stripping. Integration between the initial concentration c_0 and final concentration during any time t yields the following expression:

$$\log \frac{c_t - S}{c_0 - S} = - \frac{K'}{2.3} \left(\frac{A}{V} \right) t \quad II$$

Since the interfacial area A is subject to change

FIGURE NO. 1 STRIPPING KINETICS



throughout the depth of the tank and is extremely difficult to measure, this term is generally included in an overall K factor. Assuming that S is small compared to c_0 , equation II may be rewritten as

$$\log \frac{c_t}{c_0} = -K_a t \quad \text{III}$$

where $K_a = \frac{1}{2.3} \left(\frac{A}{V} \right)$. A semi-log plot of the remaining concentration against time yields a straight line, and K_a indicates the efficiency of the particular system under study (17, 18).

There are various factors which effect the K_a the rate of removal of ammonia. The logical approach therefore is first to study the factors effecting stripping. The materials and methods of analysis and the experimental details are described in the following pages.

CHAPTER IV

MATERIALS AND METHODS

4.1 The analysis of fertilizer waste effluents from Sindri fertilizer factory and the estimated quantities in the Panki fertilizer factory of the Indian Explosives Limited-Kanpur are given in Tables (3 and 4). Next to carbon dioxide, ammonia is in the highest concentration. In all the experiments conducted ammonium chloride was used as a source of ammonia. A concentration of 1400 mg/l as ammonia nitrogen was used throughout the experiments except in the variable concentration experiment. It was observed that the Nessler's method could not be used to determine the high ammonia concentrations which were encountered in these experiments, since it gave inconsistent results. The initial concentration of ammonia nitrogen is generally in the order of 1000 to 1500 mg/l. The concentration of ammonia was determined by micro-Kjeldhal method (19). This method was found to be easier and quicker and gave consistent results. A sketch of micro-Kjeldhal is given in Fig. 2. The procedure adopted is briefly as follows:

TABLE 3

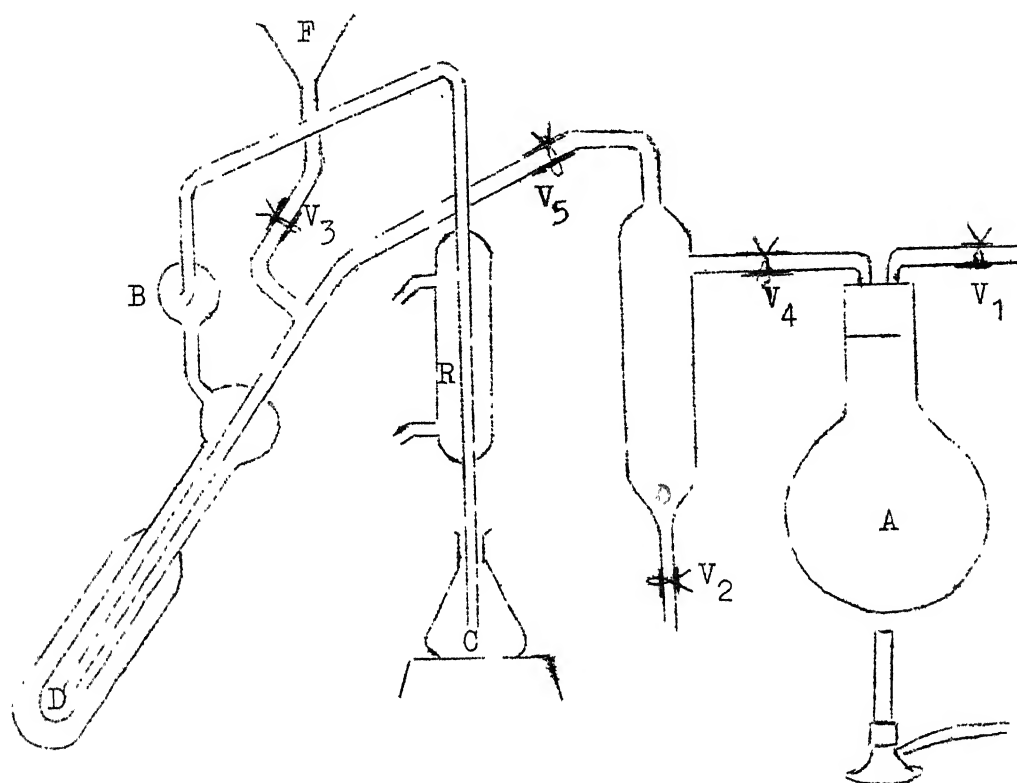
CHARACTERISTICS OF WASTEWATER AT SINDRI FERTILIZER UNIT, SINDRI

Description	Period	Constituents	Analysis in ppm		
			Max.	Min.	Ave.
Stream I	May to June, 1965	Total Phenol	8.0	0.2	1.6
		Cyanide as CN	5.0	0.05	1.5
		Amn. Nitrogen	238	7.0	88
		Suspended Solids	7190	960	3369
		Oil	24	1.0	8.2
		Flow in mgd	3.2	1.2	2.1
Stream II	May to June, 1965	Phenol	14.0	0.1	0.7
		Cyanide	3.2	0.4	1.2
		Amn. Nitrogen	939	342	313
		Suspended Solids	790	97	398
		Oil	29	2.0	11.5
		Flow in mgd	9.8	6.2	7.8

TABLE 4
ANALYTICAL CHARACTERISTICS OF UREA PLANT, KANPUR

Item		ppm
Volume	107 M ³ /hr	
Temperature	45° c	
Urea		1065
NH ₃		1410
CO ₂		1860
Other dissolved solids		1280
Total dissolved solids		2345
Suspended solids		-
Total solids		2345
Ammoniacal Nitrogen		1160

FIGURE NO. 2 MICRO-KJELDHAL APPARATUS



4.2 Tap water is circulated in the condenser 'R'. Stopcocks V_1 and V_2 in the closed position, the boiling flask 'A' with distilled water and glass beads in it, is heated. About 100 ml. of distilled water is poured in the inlet funnel 'F'. The stopcock V_3 is then closed. Then V_1 is opened and V_4 is closed when water starts boiling in the bulb 'B'. The water in the distillation flask 'D' is sucked back by vacuum into the outlet 'O'. Now the apparatus is clean and the water in the outlet is removed by opening the valve V_2 . Close V_2 after letting out the washings. After washing V_1 is closed and V_4 and V_3 are opened. The boiling flask is heated and required amount of boric acid (there should be more milliequivalents of borate ions than the expected ammonium ions to be absorbed in the boric acid) is taken in a conical flask and placed at the collecting end 'C'. Now a measured amount of the sample is pipetted out into the funnel 'F' and 10 ml of 40% sodium hydroxide solution is poured immediately into the funnel. The funnel is washed with a small quantity of distilled water and V_3 is closed. Place some distilled water in the funnel to observe any possible leakage of ammonia.

All these operations should be done as swiftly as possible to avoid any possible escape of ammonia through the funnel. Ammonia in the sample is liberated out by steam and is absorbed in the boric acid where the lavender colour is changed into green. Continue the heating until the volume of the solution in the conical flask reaches a set level (which has to be standardized earlier to see that all the ammonia is absorbed), and remove the conical flask. Remove the burner and suck back the sodium hydroxide and water in the distillation flask 'D'. Clean the distillation flask and replace the water in the boiling flask before analysing the second sample, to avoid absorbing sodium hydroxide into the boric acid. The contents of the conical flask is titrated with standard sulphuric acid and amount of ammonia nitrogen is calculated as given below:

$$\text{mg/g of ammonia nitrogen} = \frac{V_1 \text{ N } 14000}{V_2} \quad \text{IV}$$

where

V_1 = Volume of $\text{H}_2 \text{SO}_4$ used in the titration

N = Normality of $\text{H}_2 \text{SO}_4$

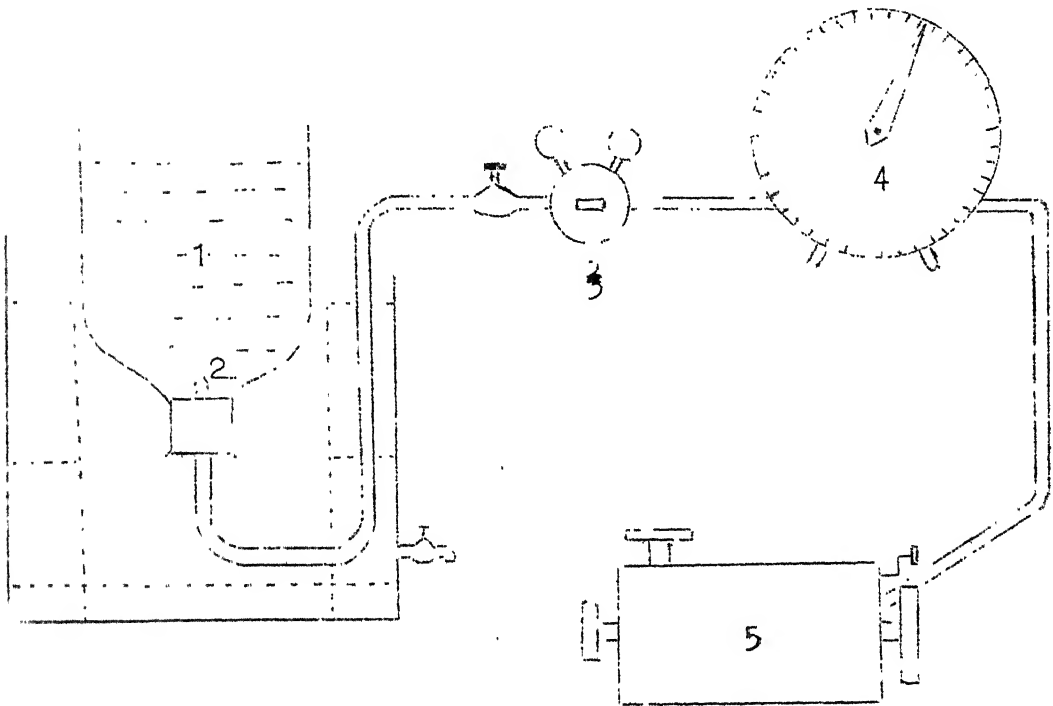
V_2 = Volume of the sample used

4.3 An inverted six litre glass bottle whose bottom was removed, had been used as the reactor vessel. A glass nozzle of $1/16$ " dia was used as the air diffuser. A 1 H.P. crompton's reciprocating pump was used as the source of air supply. Since the air pressure varies with time, a Matheson pressure regulator (Model No. 1H) was used to maintain a constant air supply. Precision scientific company's Wet test meter has been used to measure the rate of aeration. The reactor vessel is placed in a drum with bricks to give a firm support. The experimental set up is shown in Fig. 3.

4.4. As ammonia is being removed, pH will reduce and a .1 Molar sodium ortho-phosphate buffer has been used in all the experiments to keep the pH constant throughout the experiment (21). All the pH measurements were done by using Beckmen's expandomatic pH meter.

4.5 To maintain the temperature of the solution in the reactor vessel at 24°C ice was placed in the drum. To maintain the temperature to be above that of the room, an immersion heater was used. In the experiments

FIGURE NO. 3 EXPERIMENTAL SET UP



1. Reactor vessel
2. Diffuser
3. Pressure regulator
4. Wet test meter
5. Air compressor.

to find the effect of temperature, temperature was measured at regular intervals of 15 minutes to see that the temperature was being maintained at a constant level. Five runs at 24° , 33° , 40° , 46° , and 53°C were conducted to see the effect of temperature.

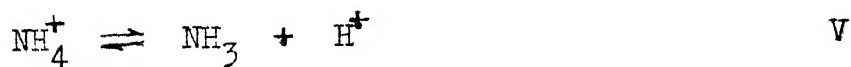
CHAPTER V

EXPERIMENTAL RESULTS AND DISCUSSION

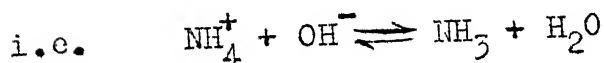
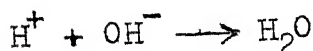
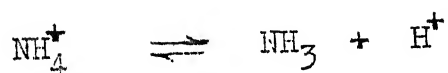
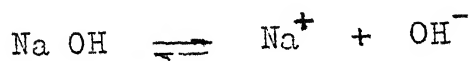
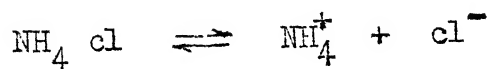
5.1 Air stripping is a physical phenomena. However since the removable compound has to be in a state that can be carried out by the gaseous phase, the behaviour of the compound itself under various physical and chemical conditions is important. Thus the behaviour of ammonia and ammonium ion under different pH values, temperature conditions, concentrations and associated chemicals is described in the following experiments.

5.2 Effect of pH:

In a solution of ammonium chloride, due to ionization the ions of ammonia and chloride are present in the solution. NH_4Cl being the salt of a weak base and a strong acid does not ionize centpercent. The ionization constant gives the extent of dissociation of the salt. NH_4^+ is a complex stable ion, and exists in equilibrium as follows (7):



Thus unless the stable NH_4^+ is converted to ammonia (NH_3), it will not be possible to remove ammonia from solution. A strong base like sodium hydroxide when added to the NH_4^+ , decreases the proton concentration (H^+) by the formation of water which is a poorly ionizing compound. Thus equilibrium in equation(V) is shifted towards right, though not completely. Ammonia can then be removed by air stripping. The equilibrium constant for removal of ammonia may be written as:



$$K = \frac{[\text{NH}_3][\text{H}^+]}{[\text{NH}_4^+][\text{OH}^-]}$$

Higher the value of K, the reaction constant,

more is the conversion of NH_4^+ to NH_3 . So the formation of ammonia (NH_3) will increase with pH. That is theoretically, the rate of removal increases with pH. ~~The rate of removal of ammonia with pH and temperature is given in the appendix.~~ However, the equilibrium is not shifted completely to the right side of the equation (V). Hence there is a limit for ammonia formation and its removal with increase in pH.

A solution of ammonium chloride whose concentration is 1500 mg/l as ammonia nitrogen has a pH value of 5.2. The rate of removal of ammonia at this pH will be very negligible. The rate of removal of ammonia with varying pH, keeping other conditions constant is given in Fig. 4. The variation of percentage reduction of ammonia with time at various pH values is shown in Fig. 5.

The rate of removal of ammonia increased upto a pH of 11, thereafter remaining almost constant. In order to obtain the pH of ~~all~~ about 6g/l of Na OH has been added. There will not be any benefit, evidently to go beyond pH of 11. The results also indicate that the reasoning of incomplete ionization as discussed

FIGURE NO. 4 VARIATION OF RATE OF REMOVAL WITH pH.

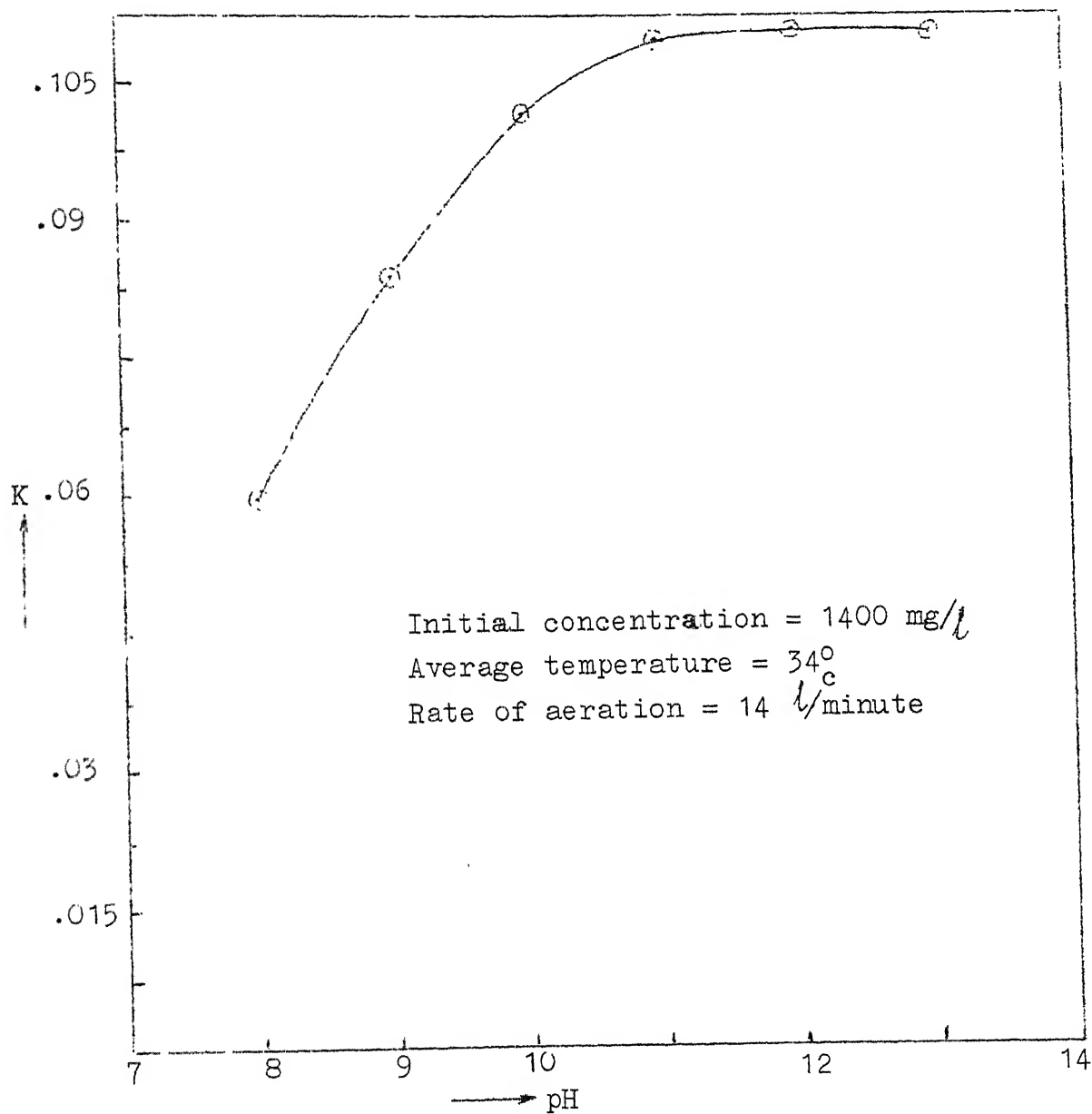
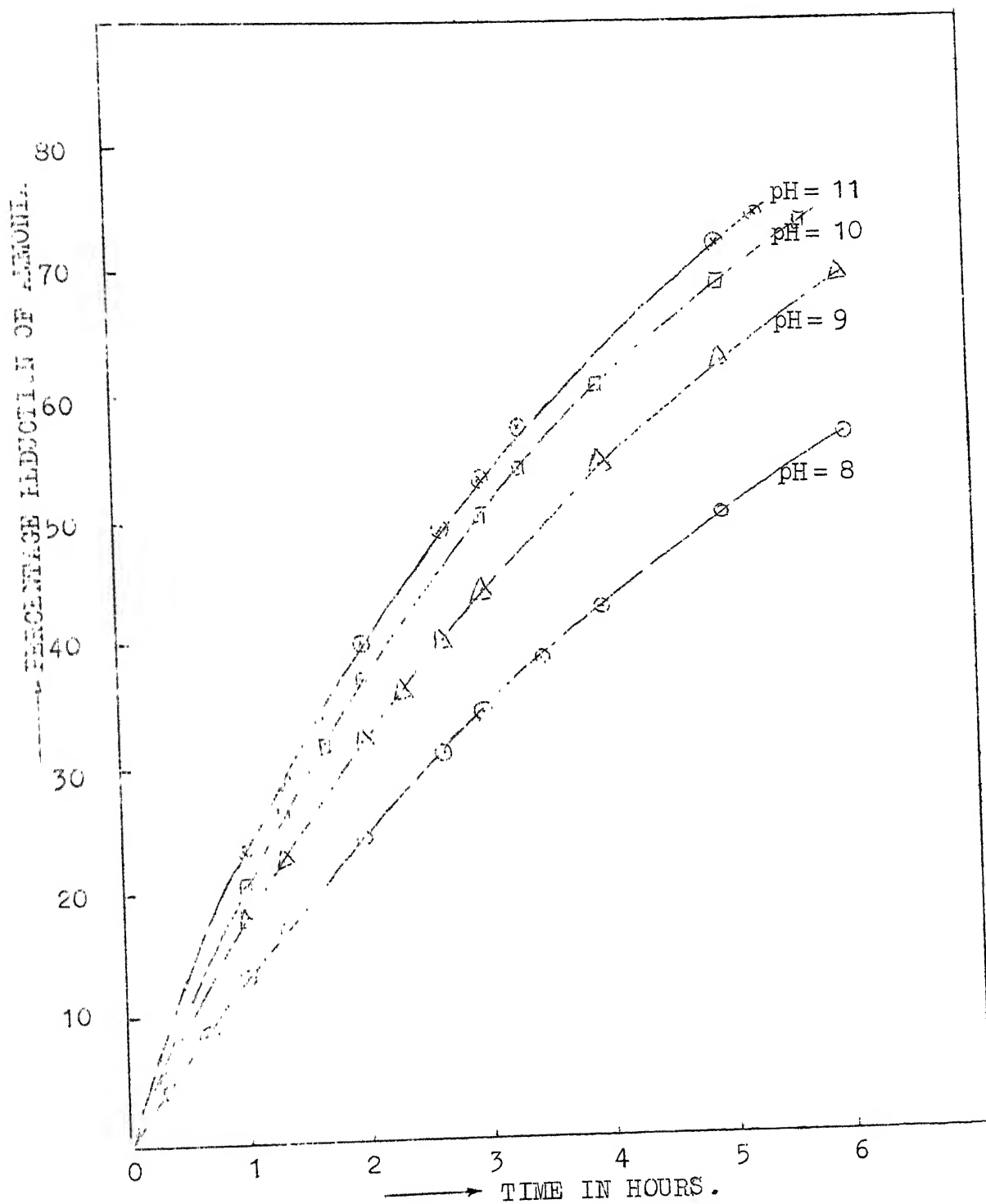


FIGURE NO.5 VARIATION OF PERCENTAGE REDUCTION OF AMMONIA WITH TIME AT VARIOUS pH VALUES.



above is valid in case of ammonia stripping.

5.3 Effect of Temperature:

Temperature effects all chemical reactions as well as the mass transfer rate of ammonia. Bhattacharya (14) has shown that in the nitrification-denitrification system of ammonia removal, 36°C is the optimum temperature and that increase in temperature will effect the enzymatic system of bacteria and retard the rate of ammonia removal. The actual temperature of fertilizer factory waste is in the range of 40 to 50°C and so the temperature of the fertilizer factory waste has to be brought down in the nitrification-denitrification system. If on the other hand, it can be proved that the rate of removal of ammonia increases with increasing temperature the method of air stripping will be more useful. To gain an insight into the magnitude of its effect, experiments have been conducted on the ammonia removal at various temperatures. Results of the experiments, where the effect of temperature is studied, are shown in Figs. 6 and 7. Information below the room temperature and above the temperature of the effluents coming out from the factory (Refer Table 5) is collected.

FIGURE NO.6 VARIATION OF RATE OF REMOVAL WITH TEMPERATURE

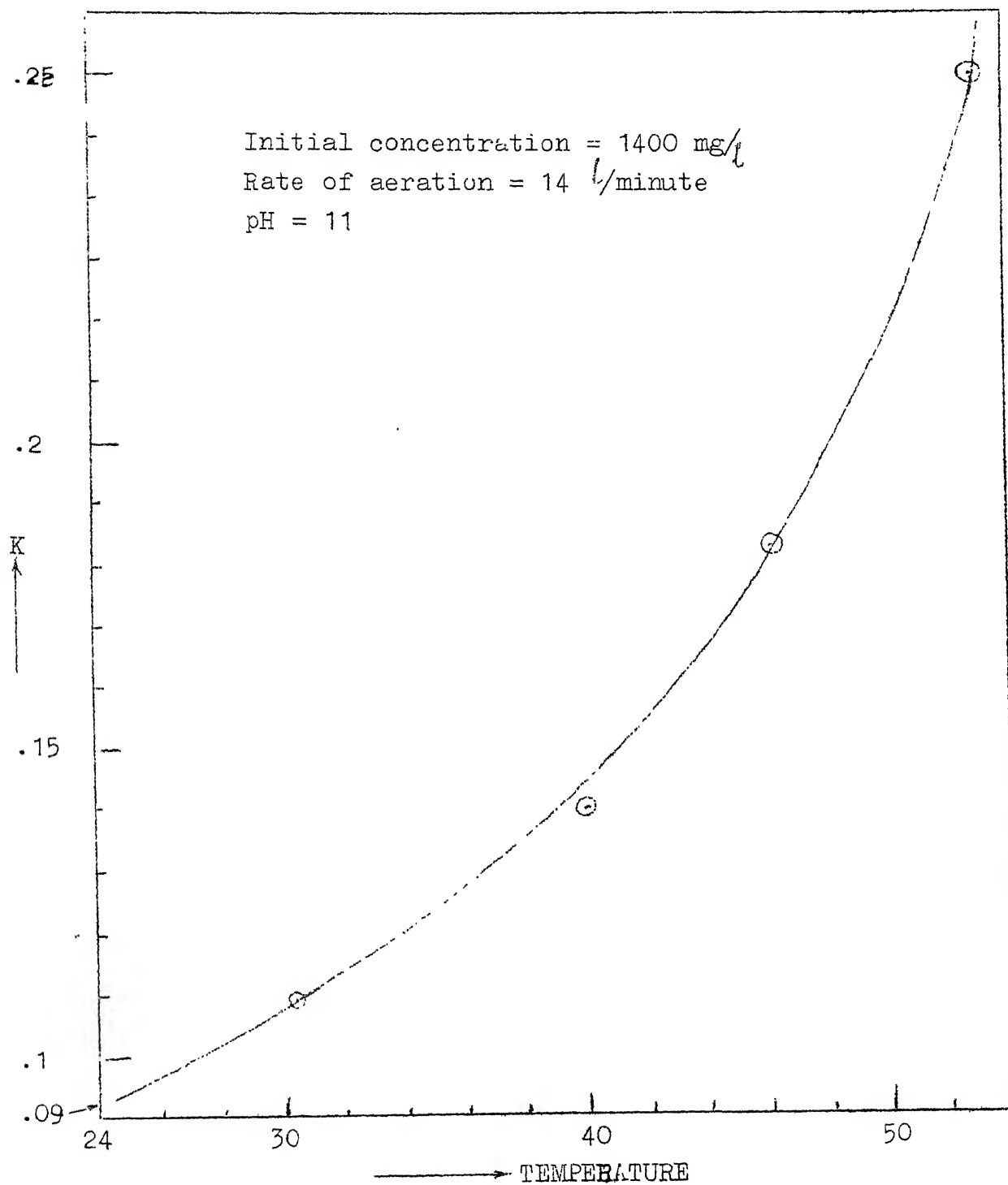


FIGURE NO.7 VARIATION OF PERCENTAGE REDUCTION OF AMMONIA

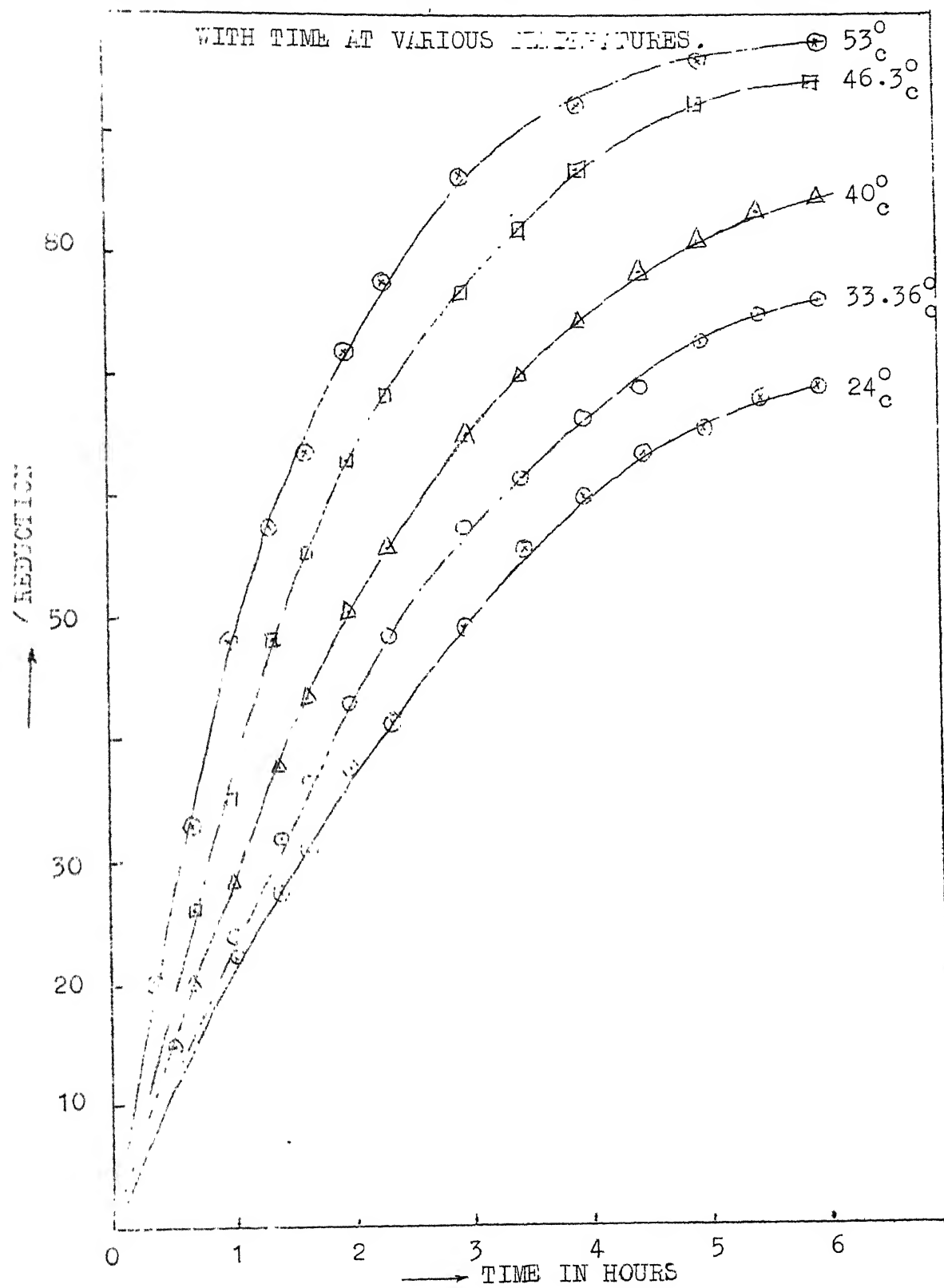


TABLE 5
K VALUES AT VARIOUS TEMPERATURES

Temperature degree centigrade	Rate of removal
24	0.0923
34	0.1091
40	0.14
46.3	0.1825
53	0.25

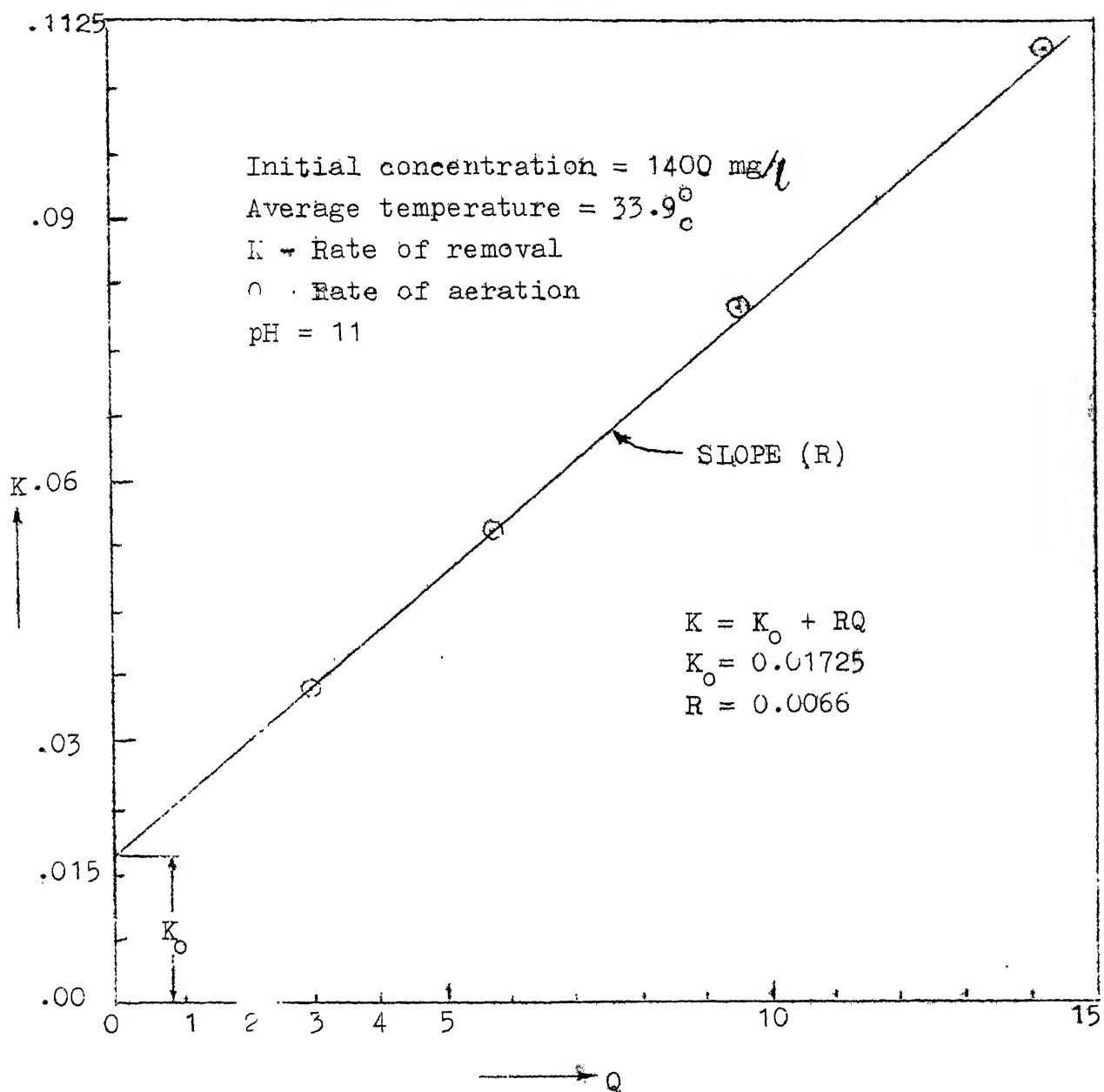
As expected the rate of removal of ammonia has increased with temperature. This information is highly useful in fertilizer industry wastes, where the temperature of the wastes will be ranging between 40°C and 50°C . No cooling of the wastes is required with air stripping since temperature has a better effect on removal of ammonia.

5.4 Effect of Rate of Aeration:

Being a mass transfer process, the rate of ammonia removal will be more with the increasing rate of aeration. Data on the effect of rate of aeration on volatile compounds of petrochemical wastes is available and it has been stipulated that the rate of removal K_a is proportional to rate of aeration (18) and that it follows the equation $K_a = K_o + RQ$ (VI)

where R is the slope of the line drawn between K_a and Q and K_o is the intercept of the line. Since no such data is available on ammonia stripping investigation is made to see whether the rate of removal and rate of aeration follow the first order equation. The data is presented in Fig. 8.

FIGURE NO.8 VARIATION OF RATE OF REMOVAL WITH
RATE OF AERATION



The relationship between the rate of removal K and unit air flow rate Q , $K = K_0 + RQ$ as given by Engelbrecht (18) held valid in the present study. Air flow rate was varied from 3 ℓ /minute to 14 litres/minute. Being a mass transfer process as the air supply increases the area available for mass transfer also increases and hence the rate of removal increases with rate of aeration. Two types of bubble formations are generally observed in aeration devices and in all aeration processes chain like bubbles (swarm of bubbles) are formed (22). For this type of bubble formation the diameter of the bubble and its ascending velocity can be calculated as given by Van Krevelen et al (23). Using Bowtra's data (15) and the bubble characteristics, it has to be investigated whether the rate of removal of ammonia can be calculated directly given the rate of aeration and tank geometry.

5.5 Effect of Initial Concentration:

The rate of ammonia removal K has to remain constant irrespective of the initial ammonia concentration, since we are using first order kinetics, to characterise the strippability of ammonia. Majumdar (12) has proved that at higher initial concentration (1400 mg/ ℓ) the

nitrifying bacteria are inhibited and the nitrification-denitrification system fails. Experiments have been conducted with various initial concentrations to see whether there is any effect of initial concentration on air stripping.

It is clearly known at this stage that the rate of ammonia removal follows first order equation and it has been experimentally verified that initial concentration has no effect on rate of removal. It has been found that the degree of ionization of the weak electrolytes is quite independent of concentration (7). The K values for four different initial concentrations are tabulated in Table 6.

In nitrification-denitrification systems there exists an inhibitory concentration of ammonia for the survival of the bacteria and the influent concentration of ammonia has to be suitably adjusted. There is no such necessity in the air stripping of ammonia.

5.6 Effect of Urea:

In all the ammonical fertilizer wastes, there exists a considerable concentration of urea (refer Tables 4. Urea readily hydrolyzes enzymatically

TABLE 6K VALUES AT DIFFERENT INITIAL CONCENTRATIONS

Initial concentration of ammonia nitrogen in mg/l	Rate of ammonia removal hr ⁻¹
728	0.1087
1400	0.1091
2772	0.1023
3659	0.1091

into ammonia and there will be an adverse effect of high urea concentration on the nitrification-denitrification system. Experiments have been conducted to see whether there is any significant effect of urea on the mass transfer of ammonia. The K values with various urea concentrations are tabulated in Table 7.

It is found that urea has no effect on the mass transfer of ammonia into air. However, the rate of ammonia removal is slightly more with urea in the synthetic sample

5.7 Effect of Changing Ammonia Source:

Experiments were conducted to see whether there was any change in the removal of ammonia by changing the ammonia source in the sample. Ammonium sulphate is used in the place of ammonium chloride. It was found that the 'K' value has not changed with the change of source. It was not expected also according to the chemical equilibria discussed before. These experiments were done to take into consideration of the wastes from ammonium sulphate fertilizer factories.

TABLE 7

K VALUES WITH DIFFERENT UREA CONCENTRATIONS

Urea concentration in mg/l	Rate of ammonia ₁ removal hr ⁻¹
1000	0.12
2000	0.12
3000	0.1
4000	0.12

5.8 Effect of Lime:

Since experimental control will be less by using lime to increase the pH, sodium hydroxide was used in all the experiments, even though lime is cheap. An experiment was conducted by using lime in place of sodium hydroxide. The fertilizer factory wastes have a considerable amount of suspended solids which will effect the process of mass transfer. By using lime the effect of suspended solids on the rate of removal of ammonia can also be observed.

To bring the pH to 11 about 6g/l of Na OH was used in experiments. The amount of lime required to raise the pH to 11 was 28 g/l. The rate of removal of ammonia (K) by using lime to raise the pH is as low as 0.05 hr^{-1} compared to the rate of removal value of 0.11 hr^{-1} by using sodium hydroxide. The usage of lime has the greatest disadvantage of forming suspended solids in the liquid which slackens the efficiency of mass transfer to a very great extent.

CHAPTER VI

CONCLUSIONS:

Based on the experimental data and discussion presented in the previous pages the following conclusions may be drawn:

- 1) Most suitable pH for air stripping of ammonia is pH 11.
- 2) The rate of ammonia removal increases with temperature.
- 3) The rate of ammonia removal follows a first order equation with the rate of aeration.
- 4) Initial concentration has no effect on the rate of ammonia removal.
- 5) Urea has no effect on the rate of ammonia removal.
- 6) A change in ammonia source has also no effect on ammonia removal.
- 7) Treatment with lime to raise the pH is not as effective as the treatment with sodium hydroxide.

CHAPTER VII

SUGGESTIONS FOR FURTHER WORK

- 1) Work on air-stripping of ammonia should be done under steady state conditions.
- 2) A comparison of air requirements should be made between open tank and closed column systems.
- 3) Research should be carried out to find the rate of removal of ammonia directly, by knowing the tank geometry, bubble characteristics and rate of aeration for easy design of treatment plants.

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APPENDIX

Theoretically the variation of the rate of removal with pH and temperature can be evaluated as follows:



$$K_{eq} = \frac{[\text{NH}_3]}{[\text{NH}_4^+][\text{OH}^-]}$$

$$\therefore [\text{NH}_4^+] = \frac{[\text{NH}_3]}{K_{eq}[\text{OH}^-]} \quad \text{--- (1)}$$

But C_t the concentration of total ammonia nitrogen measured at any time t is given by

$$C_t = [\text{NH}_3] + [\text{NH}_4^+] \quad \text{--- (2)}$$

From (1)

$$C_t = \text{NH}_3 \left\{ 1 + \frac{1}{K_{eq}[\text{OH}^-]} \right\}$$

$$\text{pH} + \text{pOH} = 14$$

$$\therefore [\text{OH}^-] = 10^{\text{pH} - 14}$$

$$\therefore C_t = \text{NH}_3 \left\{ 1 + \frac{1}{K_{eq} 10^{\text{pH} - 14}} \right\}$$

$$\therefore [\text{NH}_3] = \frac{C_t}{1 + \frac{1}{K_{eq} 10^{\text{pH}-14}}}$$

$$\text{But } -\frac{dC_t}{dt} = K_a [\text{NH}_3]$$

$$= K_a \frac{C_t}{1 + \frac{1}{K_{eq} 10^{\text{pH}-14}}}$$

$$= K_a P C_t \text{ where } P = \frac{1}{1 + \frac{1}{K_{eq} 10^{\text{pH}-14}}}$$

~~Various~~ values of P at various pH values and temperatures are tabulated in tables 8 and 9. Theoretical variation of P with pH and temperature is shown in figures 9 and 10.

TABLE 8
P values at various pH values

pH	P	log P
7	1.849×10^{-11}	-11.2669
8	1.849×10^{-10}	-10.2669
9	1.849×10^{-9}	-9.2669
10	1.849×10^{-8}	-8.2669
11	1.849×10^{-7}	-7.2669
12	1.849×10^{-6}	-6.2669
13	1.849×10^{-5}	-5.2669

TABLE 9
P values at various temperatures

TEMPERATURE DEGREES CENTIGRADE	P	log P
0	1.376×10^{-8}	-8.138
20	1.710×10^{-8}	-8.233
35	1.849×10^{-8}	-8.2669
40	1.862×10^{-8}	-8.27
50	1.892×10^{-8}	-8.277

FIGURE 9 THEORETICAL VARIATION OF RATE OF REMOVAL WITH pH
AT 35°C

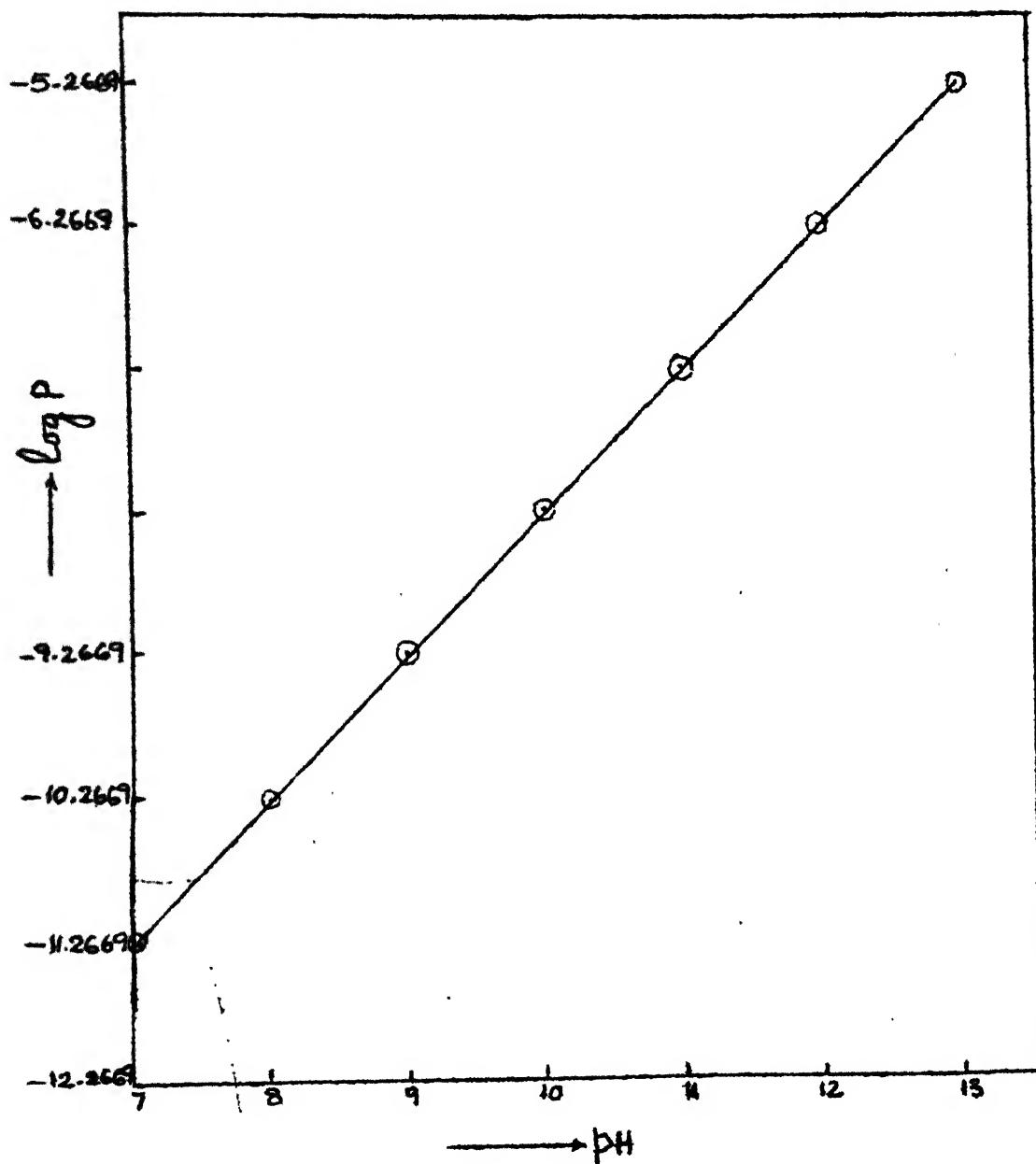


FIGURE 10 THEORITICAL VIRIATION OF RATE OF REMOVAL
WITH TEMPERATURE AT pH=4.

